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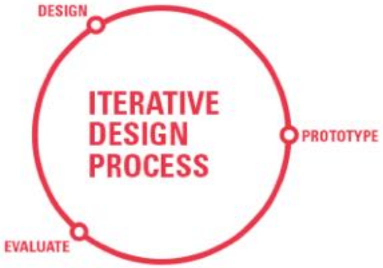
Human Reliability Analysis

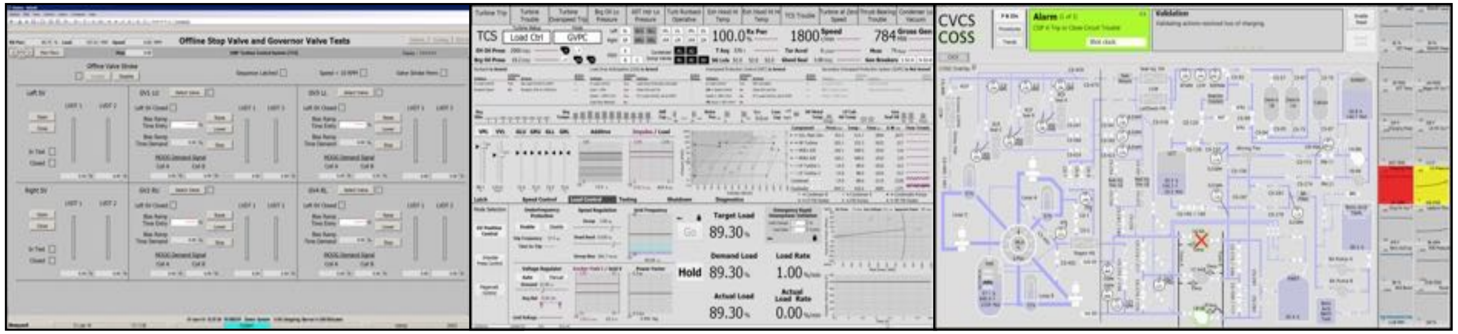
What Do Humans Have to Do with RELAP5?

Idaho National Laboratory

What Do I Do?

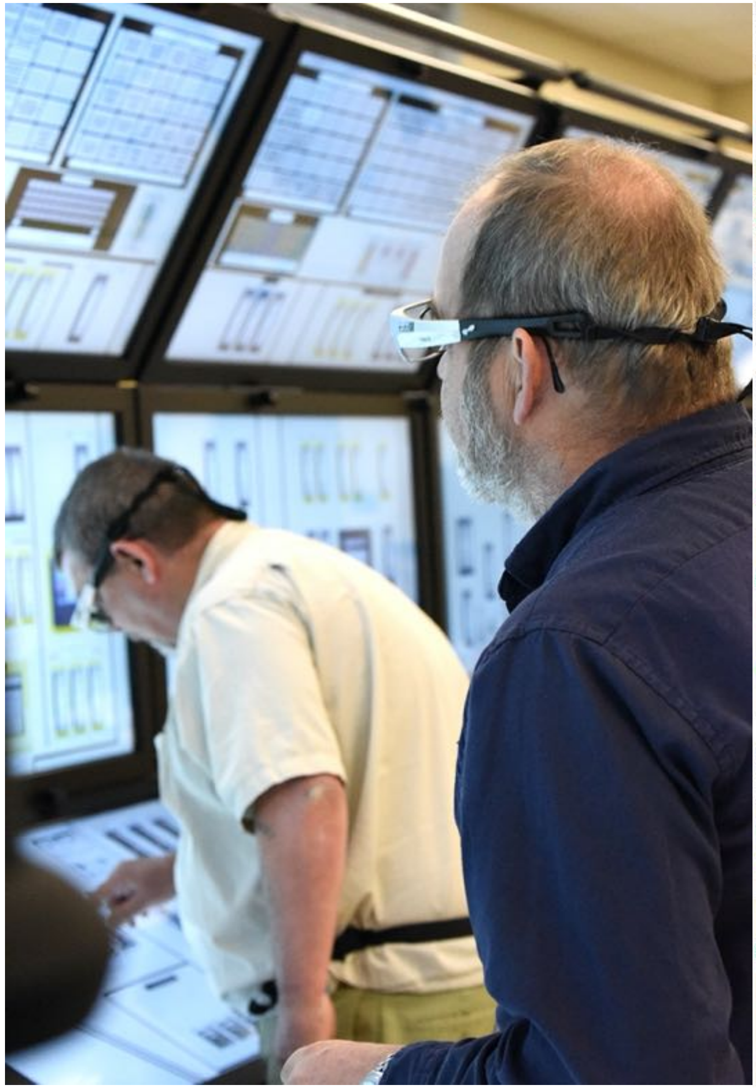

DESIGN
ITERATIVE DESIGN PROCESS
PROTOTYPE
EVALUATE

my team and I ***build prototypes*** of control rooms for nuclear power plants that we then ***evaluate*** through operator-in-the-loop studies



Build Prototypes with Simulators

Evaluate Human-System Interaction with Simulators



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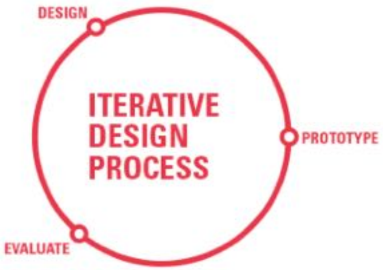
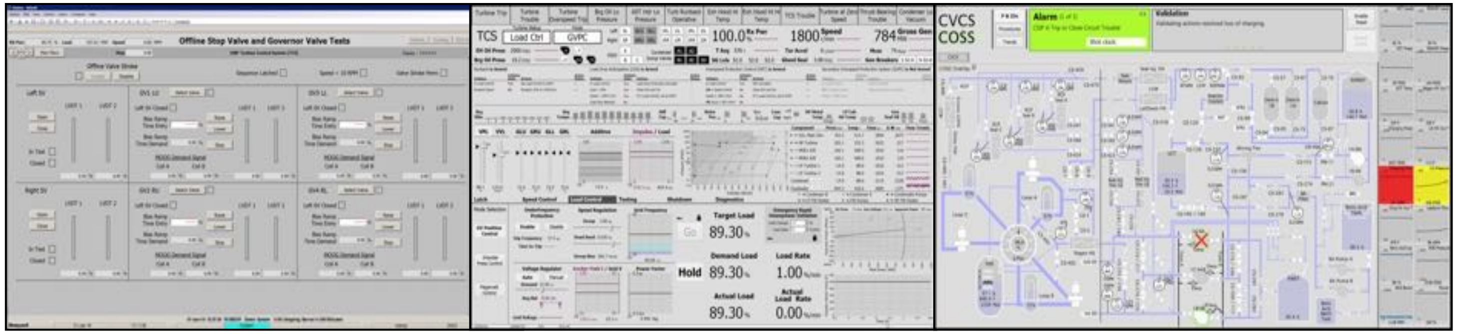


my team and I ***build prototypes*** of control rooms for nuclear power plants that we then ***evaluate*** through operator-in-the-loop studies

This is the empirical side. Increasingly, we are also asked to **predict** human performance. This involves modeling and simulation. Not only using existing tools, but also developing new models of virtual humans.



Humans are a Necessary Part of Complex Systems

Humans

- Design the systems
- Build them
- Operate them
- Maintain them
- Decommission them
- *Break* them

What happens when

- Humans do something wrong?
- Humans fail to do something required?
- Humans do something too slow?

T/H outcomes fundamentally depend on humans performing the correct plant actions!

Human Error is Significant Part of Risk

Percent of Incidents Where Human Error Was a Root Cause

90%	Maritime Industry
80-90%	Chemical Industry
60-87%	Airline Industry
65-85%	Commercial Nuclear Industry

Source: Gertman and Blackman (1994)

Medical Error

- A study conducted in 2000 by U.S. National Academies suggested medical error result in 44,000 to 100,000 accidental deaths each year and as many as 1,000,000 accidental injuries

Terminology

Human Error

- *NUREG-2122:* Any human action, including inaction, which exceeds some limit of acceptability, excluding malevolent behavior
- *ASME/ANS RA-Sb-2013:* Any human action that exceeds some limit of acceptability, including inaction where required, excluding malevolent error

Human Failure Event (HFE)

- *ASME/ANS RA-Sb-2013:* A basic event that represents a failure or unavailability of a component, system, or function that is caused by human inaction, or an inappropriate action

Don’t Be Afraid of Error

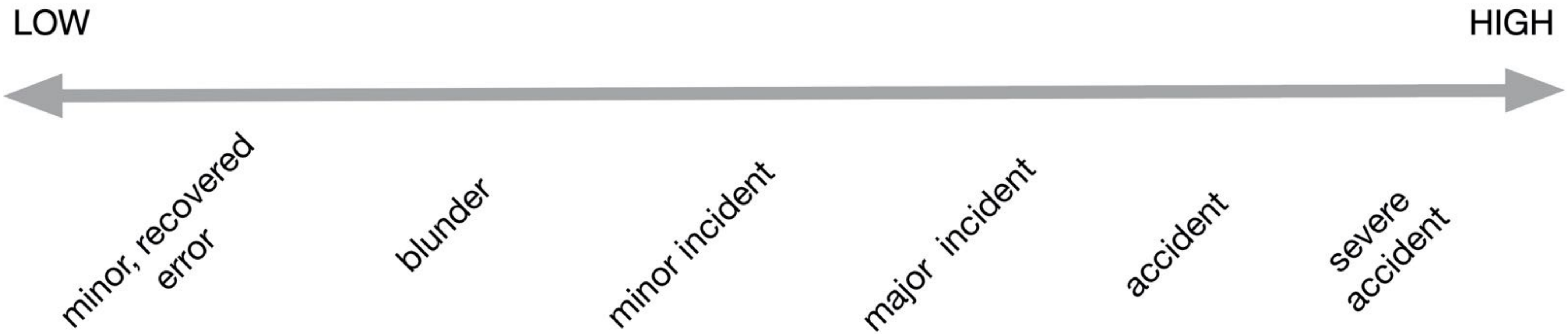
To Err is Human

- Every human action is subject to imperfection
- Even highly trained, highly skilled actions tend to fail 1 out of 100 to 1 out of 1000 times
- Certain contextual factors may increase or decrease that likelihood of error
- The same qualities that make human actions error-prone also afford resilience
  - **Humans spontaneously recover from most errors**
    - Internal self-monitoring and external feedback loops help correct course
    - e.g., catching yourself while mispronouncing a word
    - e.g., correcting while starting to lane drift while driving
  - **Most human errors aren’t single-point failures**
    - Actions are part of a bigger sequence of activities with checks and corrections

Different Consequences

Not Every Error is Equally Consequential

ECONOMIC AND SAFETY CONSEQUENCE



LOW

HIGH

minor, recovered error

blunder

minor incident

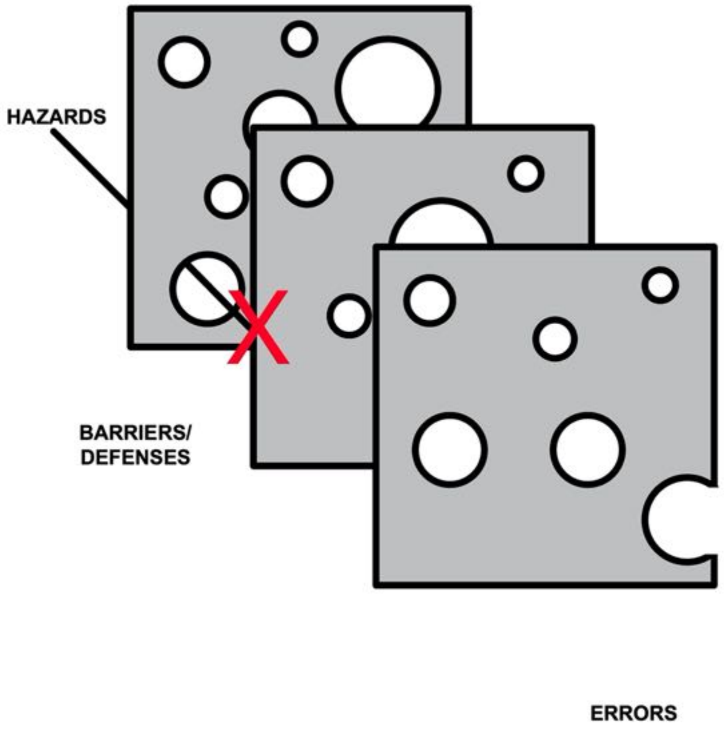
major incident

accident

severe accident

Swiss Cheese Model

- James Reason (1990) suggested that for an accident to happen, there typically have to be many human and hardware failures
- No system can be completely free of opportunities for failures, and there is always opportunity for errors to slip through



Defense in Depth

- An approach to designing and operating nuclear facilities that prevents and mitigates accidents that release radiation or hazardous materials
- The key is creating multiple independent and redundant layers of defense to compensate for potential human and mechanical failures so that no single layer, no matter how robust, is exclusively relied upon

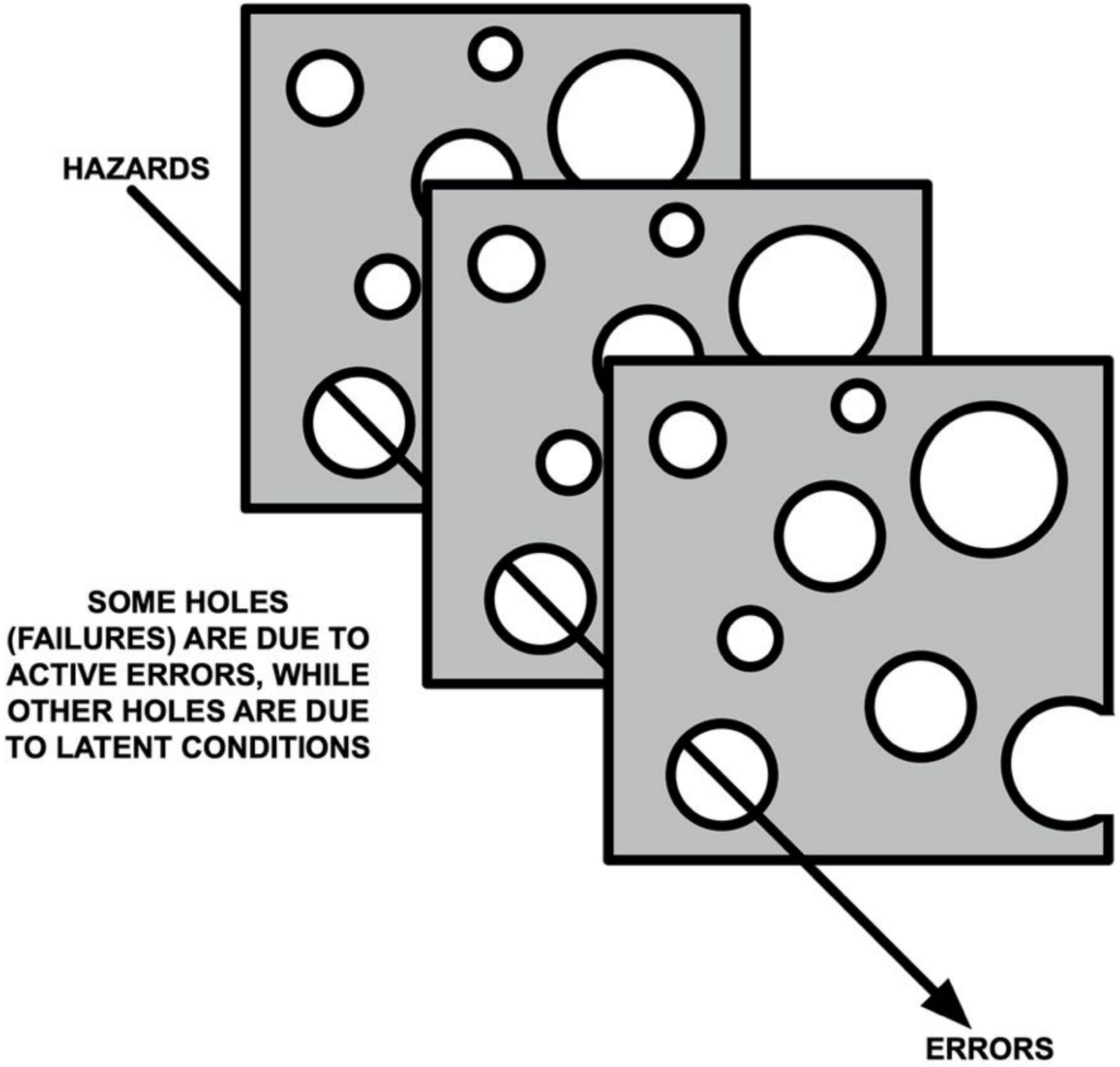
Active vs. Latent Errors

Active Errors
(Something Hit the Fan!)

- Unsafe acts, failures of technological functions, or human errors that become the local triggering events that cause immediate negative effects on the situation

Latent Errors
(Accident Waiting to Happen!)

- They are present within the system as unnoticed conditions well before the onset of a recognizable accident sequence



Definition of HRA

Human Reliability Analysis

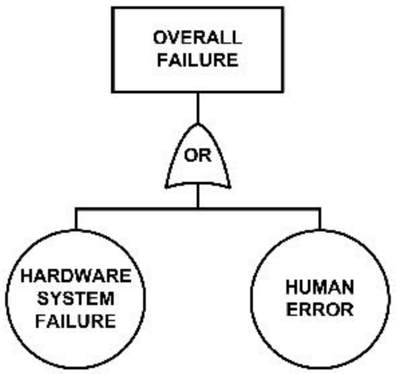
- *General Definition:* A study of human contribution to overall risk when interacting with a system
  - Part of probabilistic risk assessment (PRA) that includes hardware and human reliability
- *ASME RA-Sb-2013:* A structured approach used to identify potential human failure events and to systematically estimate the probability of those events using data, models, or expert judgment
- HRA makes up part of probabilistic risk assessment (PRA) submitted as part of licensing
- HRA is fundamentally about **predicting human error given specific contexts**

HRA Integrates with PRA

Human and Hardware Contributions to Overall Risk

- Human is a "component" in the overall system

FAULT TREE



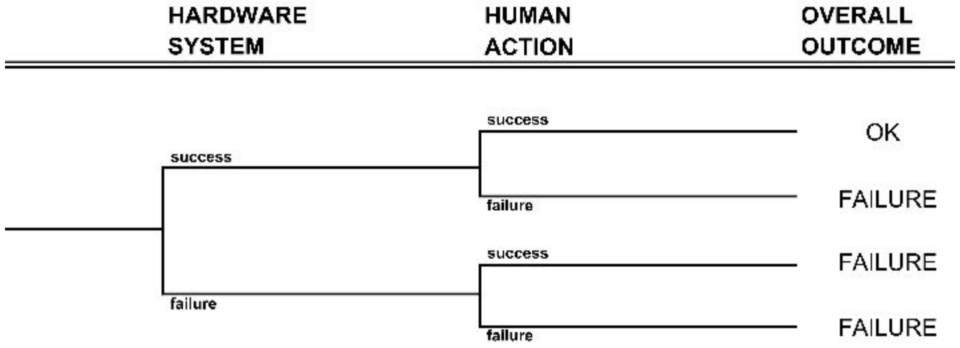
OVERALL FAILURE

OR

HARDWARE SYSTEM FAILURE

HUMAN ERROR

EVENT TREE



HARDWARE SYSTEM

HUMAN ACTION

OVERALL OUTCOME

success

failure

success

failure

success

failure

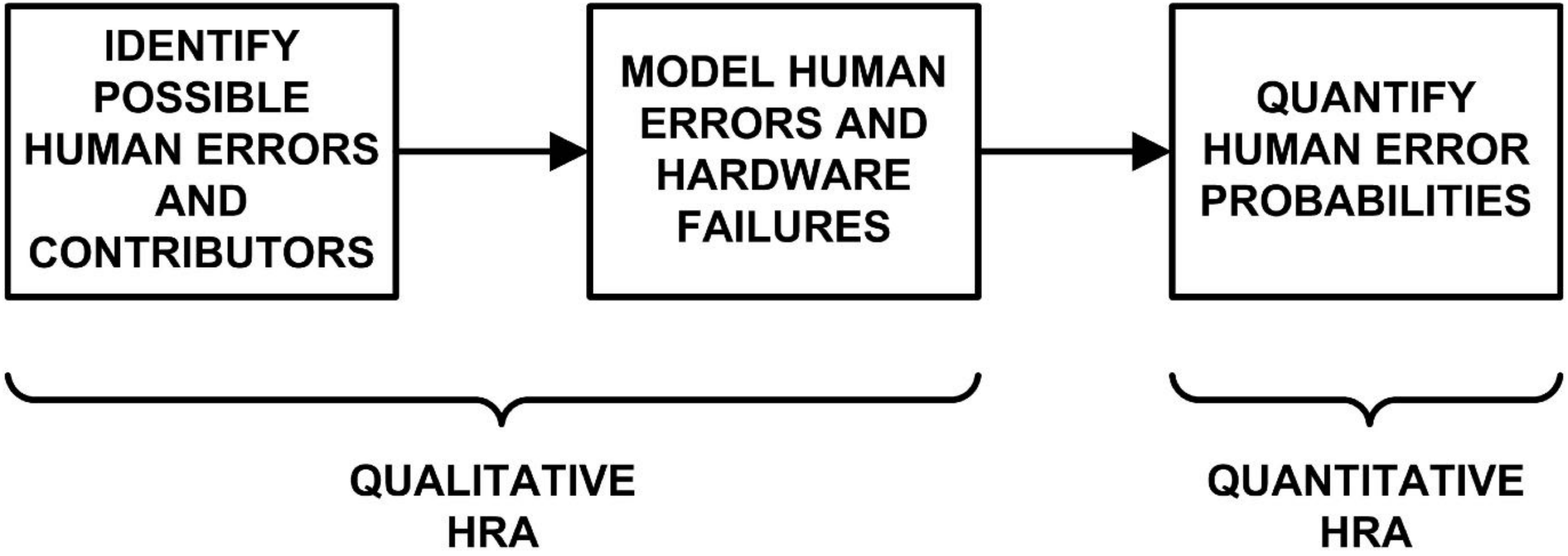
OK

FAILURE

FAILURE

FAILURE

Basic Steps of Human Reliability Analysis



IDENTIFY POSSIBLE HUMAN ERRORS AND CONTRIBUTORS

MODEL HUMAN ERRORS AND HARDWARE FAILURES

QUANTIFY HUMAN ERROR PROBABILITIES

QUALITATIVE HRA

QUANTITATIVE HRA

Performance Shaping Factors (PSFs)

Definition

- Those factors that influence the performance and error likelihood of human activities
- They capture the context surrounding an activity
  - **Internal PSFs**—human attributes such as skills, abilities, and attitudes that operate within the individual and are brought to the job by the individual
  - **External PSFs**—aspects of situations, tasks, and plant characteristics that influence the ability of the human to carry out activities
- PSFs may enhance performance
  - e.g., good procedures, training, and HMIs help the operator navigate a plant upset condition
- PSFs may degrade performance
  - e.g., high complexity and high stress tend to slow operator response

PSFs in Augmented Inspection Team (AIT) Reports

Human Error Type	**AIT**
Procedures	65%
Training	40%
Supervision	43%
Human Engineering	40%
Communications	35%
Management & Organization	83%
Individual Issues	38%
Workload	10%
System Design	58%
Work Environment	8%

Source: NUREG/CR-6753 (2002)

How PSFs Quantify

A Nominal Error Rate for a Particular Type of Activity is Multiplied by a PSF Level

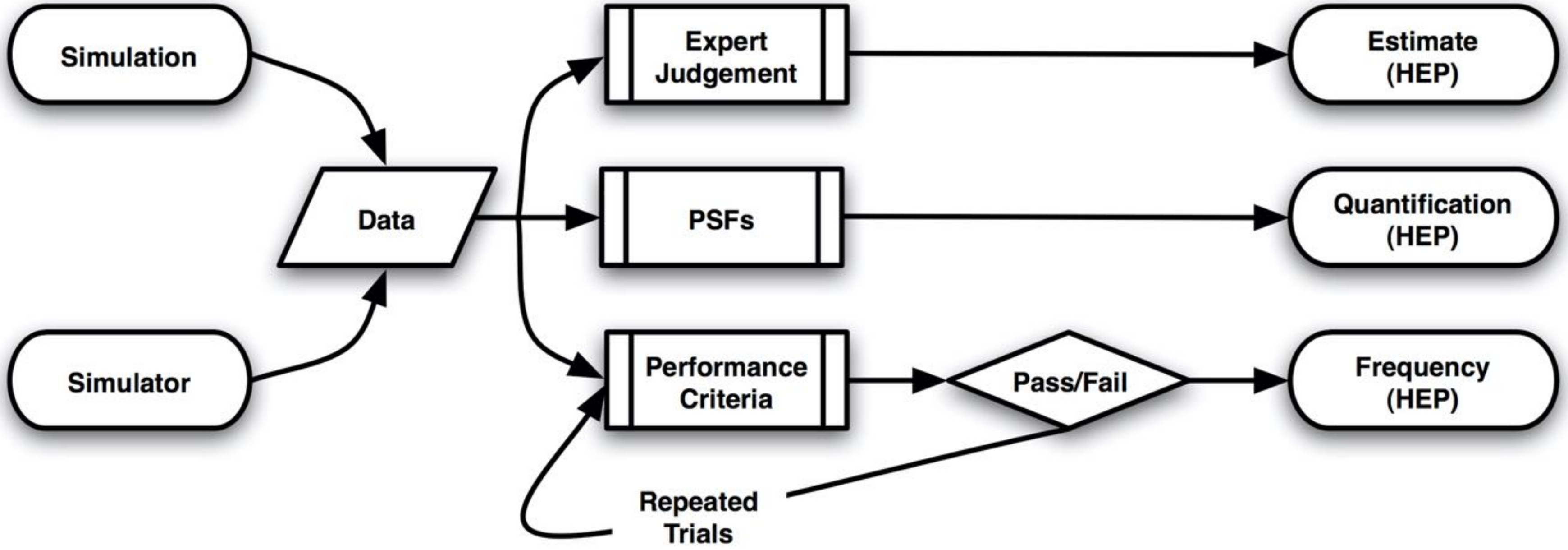
PSF	PSF Level	Multiplier for Diagnosis	Multiplier for Action
Available Time	Inadequate time	P(failure) = 1.0	P(failure) = 1.0
	Barely adequate time	10	10
	Nominal time	1	1
	Extra time	0.1	0.1
	Expansive time	0.01	0.01
	Insufficient Information	1	1

Source: NUREG/CR-6883 (2005)

Definition of Dynamic HRA

RELAP5

- HRA that uses simulation of systems and humans to predict evolution and different possible event outcomes
- Simulation: virtual environment + virtual human



Reasons for Dynamic HRA

Modeling fidelity

- Potentially higher fidelity reflection of human activities

Individual differences

- Modeling actual range of operators better accounts for performance variability than does *uncertainty* calculation

Post-accident evolution

- Accidents are not the end state; they are beginning of process, often outside pre-scripted procedures

Unexampled events

- *Stuff* happens, often beyond what we ever imagined, and it would be nice to be able to look ahead when it happens

INL Dynamic HRA Approach

Take static HRA approach and make dynamic

- Move beyond worksheet approaches and create dynamic model of operator
- Adapt static HRA method (e.g., SPAR-H) to dynamic model that can interface with INL codes

Test assumptions of static method when made dynamic

- Static HRA is analyzed at the Human Failure Event (HFE) level
  - e.g., failure to initiate safety injection
- Dynamic HRA requires sub-task modeling
  - e.g., individual procedure steps behind safety injection
  - Translating event-level methods to sub-task level

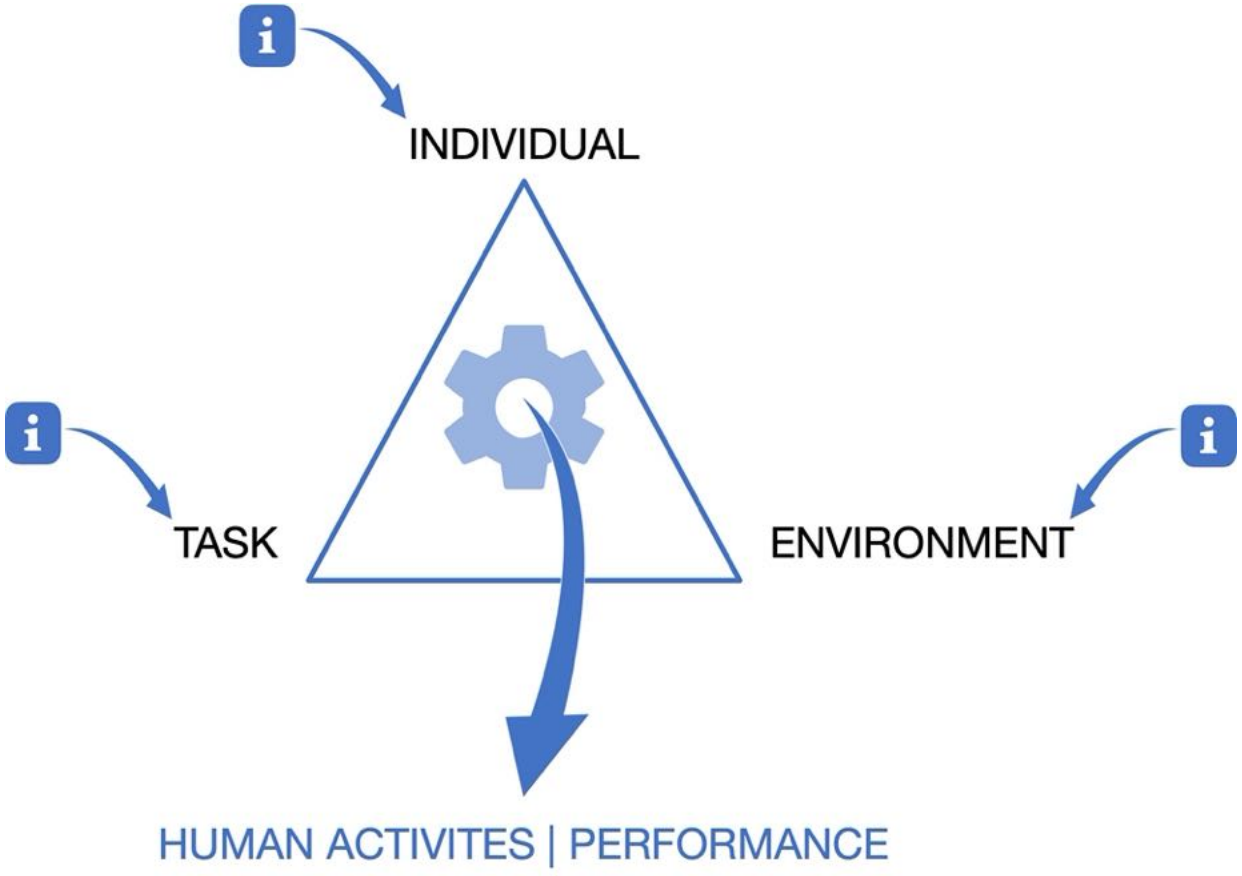
Tie into thermo-hydraulics plant models at Idaho National Lab

- MOOSE: mutiphysics problem solver engine
- RAVEN: RELAP thermo-hydraulics mixed with PRA

Our Framework

- **HUNTER: Human Unimodel for Nuclear Technology to Enhance Reliability**
  - A *unimodel* is a cognitive framework that favors simplified decision models
  - This will produce the MOOSE-HUNTER or RAVEN-HUNTER system
  - (We’re looking for a friendlier mascot, as we do not want to kill any of these code animals)

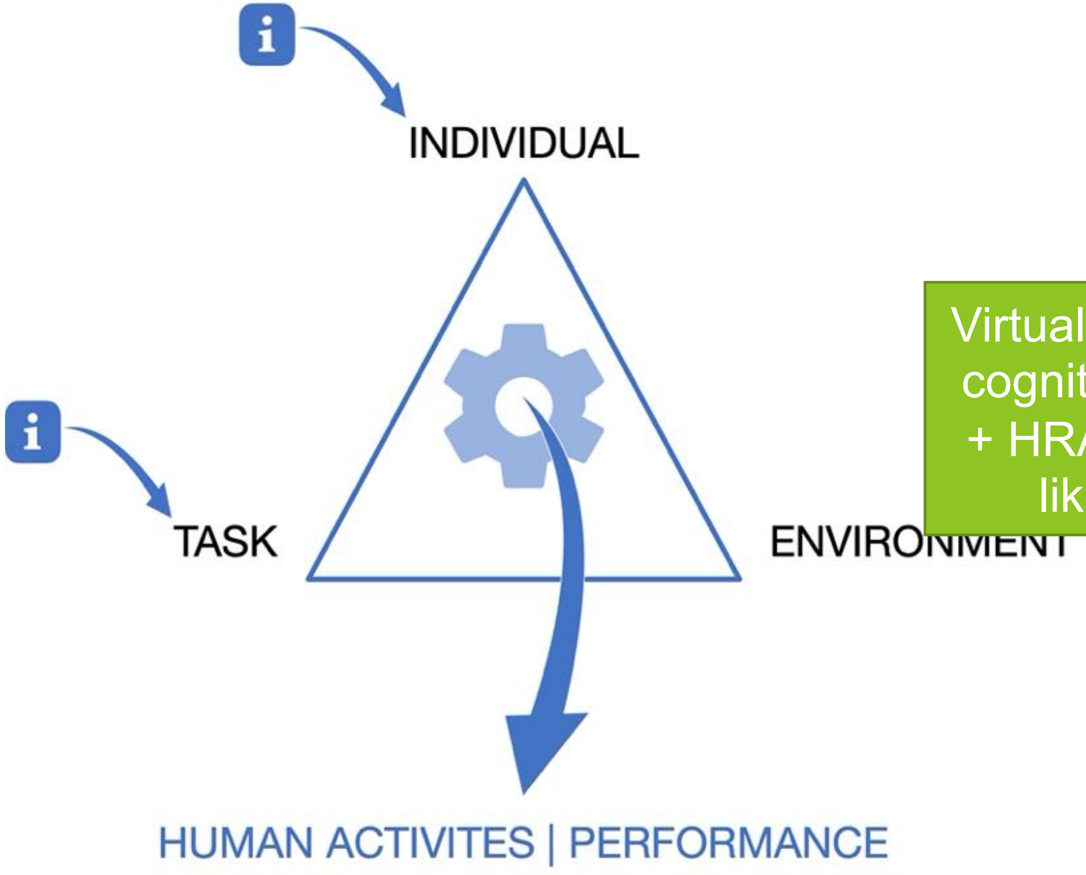
HUNTER Conceptual Framework



Two Primary Types of Elements

- ***Modules*** represent the who, what, and where
  - Individual
  - Task
  - Environment
- ***Classes*** represent how, why, and when the modules act
  - Inputs
  - Scheduler
  - Processor
  - Outputs

HUNTER Conceptual Framework



Virtual Operator = cognitive models + HRA elements like PSFs

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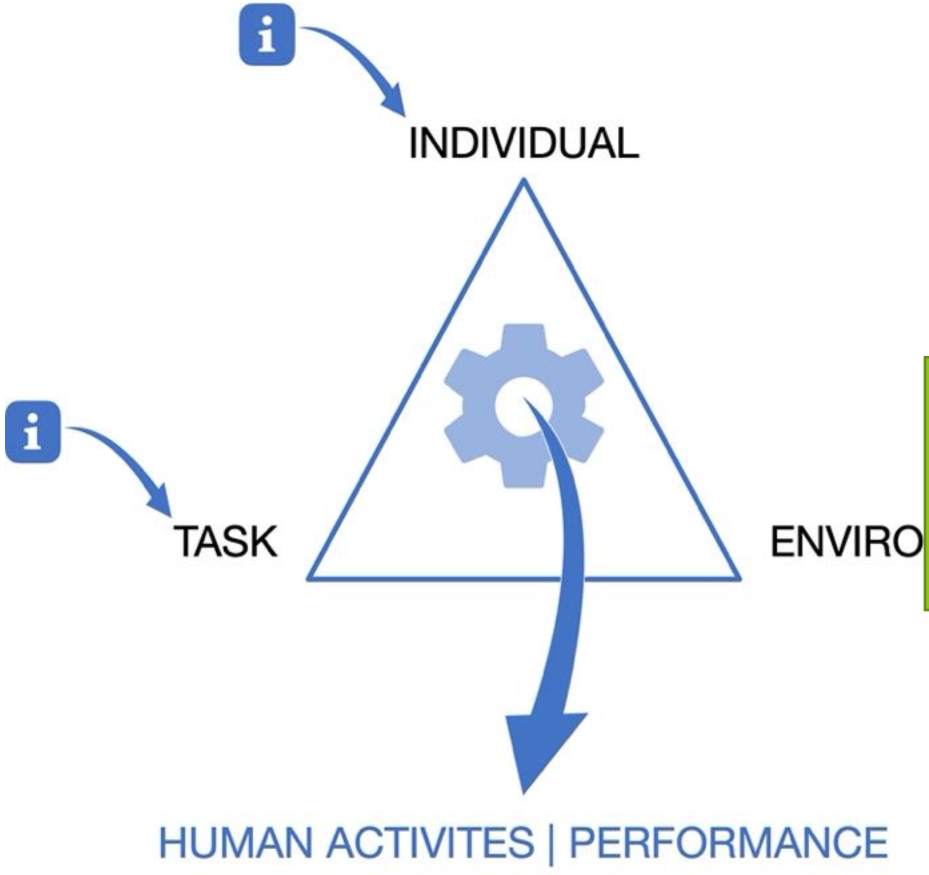

Task = Procedures (in simplest implementation)

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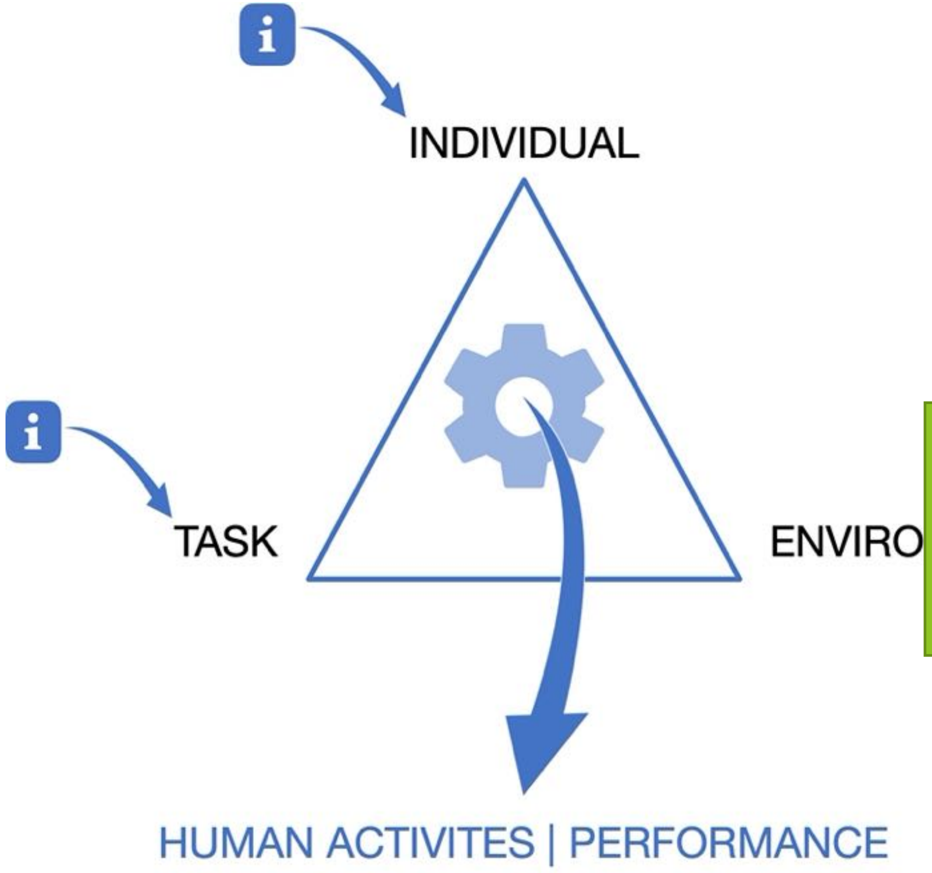

Virtual World = RELAP5/Full-scope plant model/Microworld

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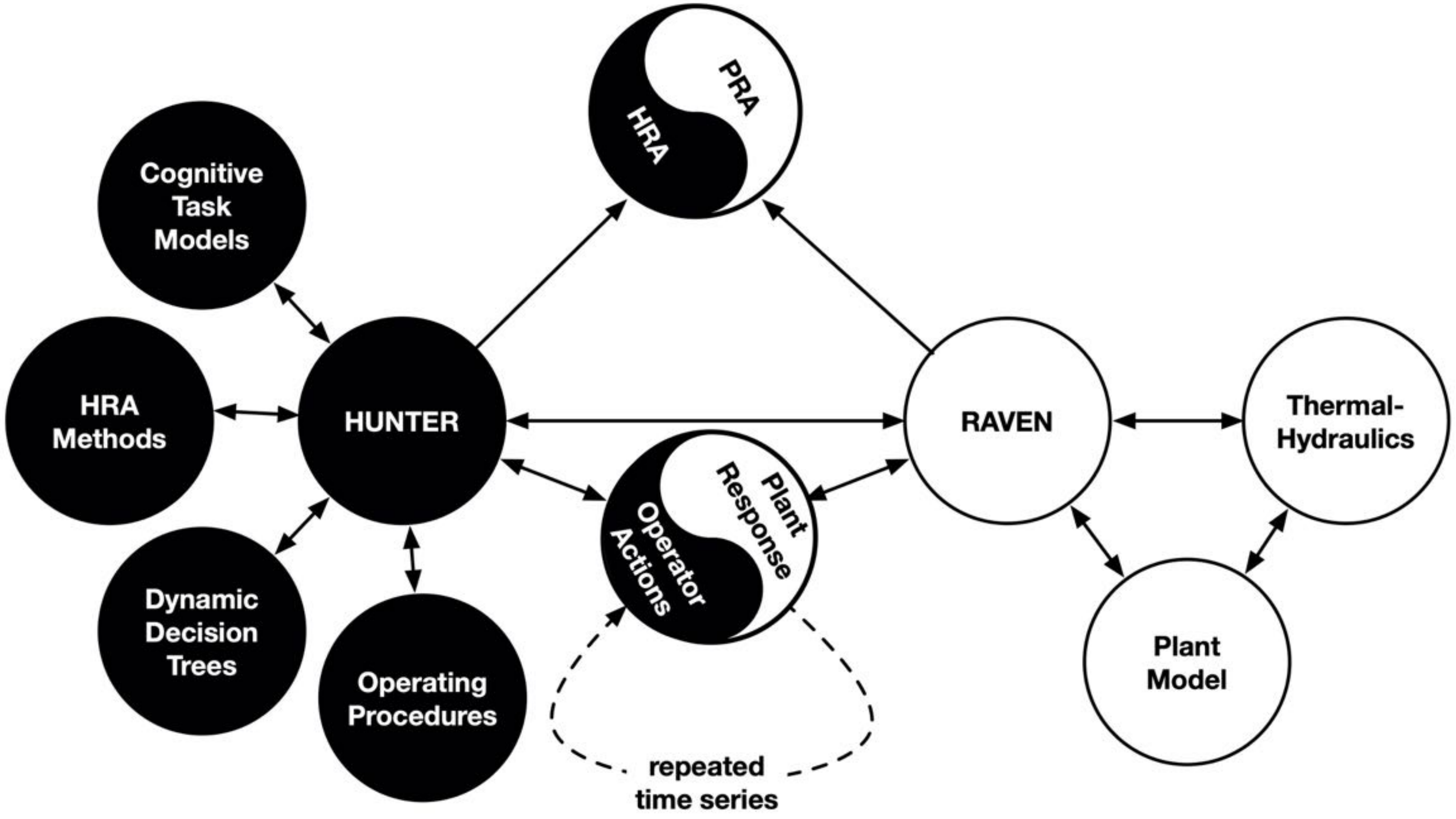
HUNTER Software Implementation (In Progress)



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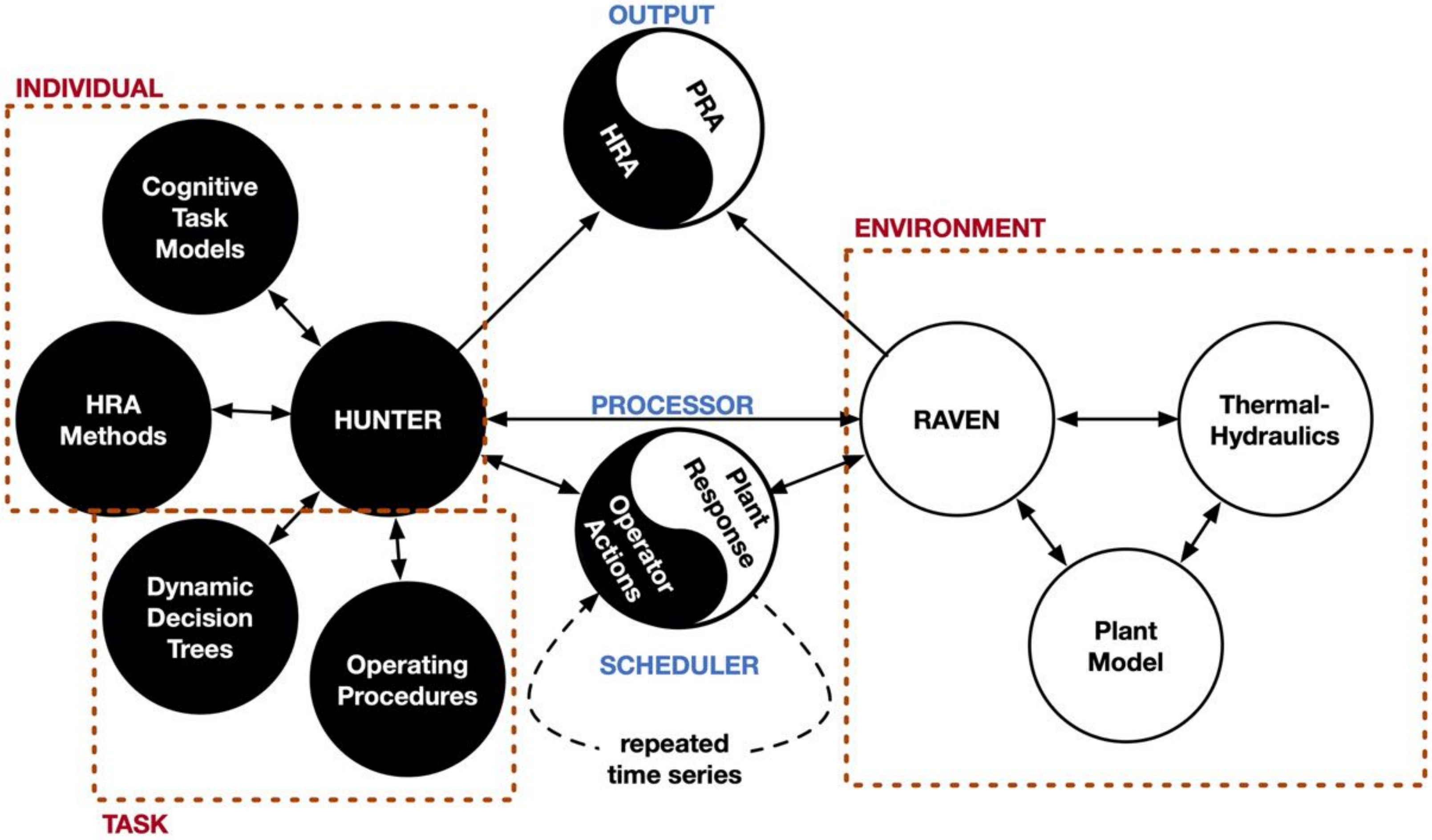
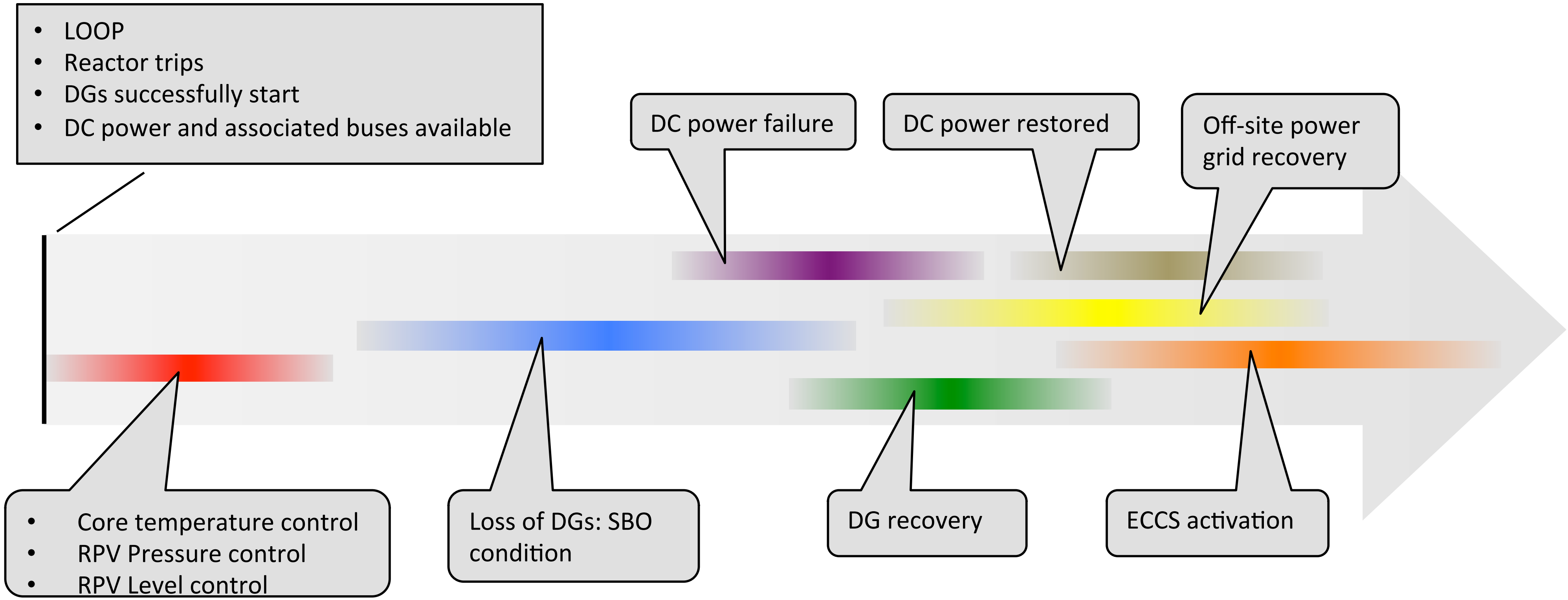


Example Application: Station Blackout



- LOOP
- Reactor trips
- DGs successfully start
- DC power and associated buses available

DC power failure

DC power restored

Off-site power grid recovery

- Core temperature control
- RPV Pressure control
- RPV Level control

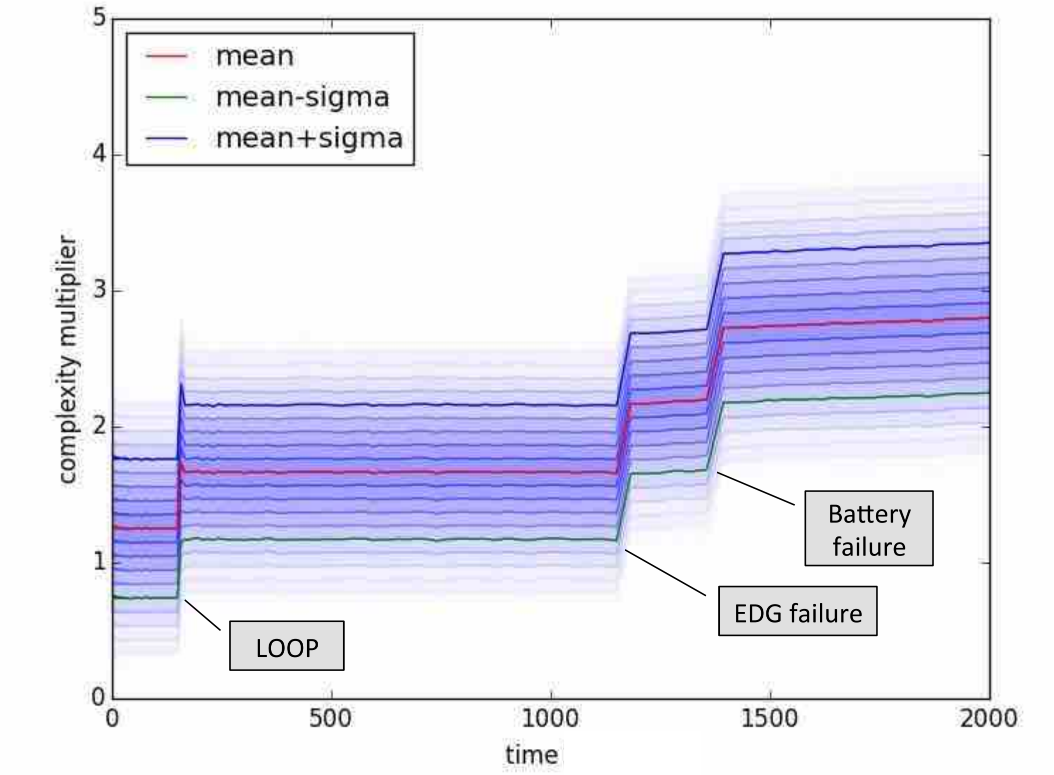
Loss of DGs: SBO condition

DG recovery

ECCS activation

Using Plant Parameters from RELAP5 to Determine Complexity PSF Multiplier

Task	LOOP	LODG	LOB	Reactor Temperature	Reactor Power Level	SME Complexity	Calculated Complexity	Normalized Complexity
1	0	0	0	566.69	100.00	1	-2.57	1.00
2	0	0	0	565.00	99.99	1	-2.56	1.00
3	0	0	0	568.69	100.00	1	-2.57	1.00
4	0	0	0	567.44	99.99	1	-2.57	1.00
5	1	0	0	540.28	3.15	3	4.40	2.77
6	1	0	0	539.92	2.95	3	4.40	2.77
7	1	0	0	539.49	2.79	3	4.40	2.77
8	1	0	0	561.59	2.38	3	4.39	2.76
9	1	0	0	538.57	2.48	3	4.41	2.77
10	1	0	0	538.55	2.63	3	4.41	2.77
11	1	0	0	538.55	2.63	3	4.41	2.77
12	1	0	0	538.55	2.63	3	4.41	2.77
13	1	1	0	575.73	1.36	4	9.40	4.03
14	1	1	0	624.89	1.29	4	9.35	4.02
15	1	1	1	1775.04	0.75	5	13.21	5.00
16	1	1	1	2092.49	0.66	5	12.89	4.92
17	1	1	1	2257.35	0.60	5	12.73	4.88
18	1	1	1	2374.40	0.54	5	12.61	4.85
19	1	1	1	2407.60	0.00	5	12.59	4.84
20	1	1	1	2400.87	0.51	5	12.59	4.84



$$
\begin{aligned}
&\mathit{Normalized\ Complexity} \\
&\quad = 1.26754 \times \mathit{LOOP} + 1.26753 \times \mathit{LODG} + 1.26753 \times \mathit{LOB} \\
&\quad - 0.00025 \times \mathit{temperature} - 0.00507 \times \mathit{power} + 1.65116
\end{aligned}
$$

Challenges of HUNTER Modeling

How to Couple Virtual World and Virtual Operator

- Batch coupling (RAVEN)
  - Determine human actions a priori and use as inputs to RELAP5
- Tight coupling (Discrete Event Simulation)
  - Have step-by-step interactions
    - Human takes action (e.g., operator turns on feedwater pump)
    - Plant responds to action (e.g., reactor temperature goes down)
    - Human takes respondent action (e.g., operator adjusts rod position)
    - Etc.
  - This approaches using RELAP5 like a simulator that dynamically responds to evolving conditions
  - Used in a Monte Carlo fashion with repeated runs that manipulate range of operator actions
- API for coordinating HUNTER and RELAP5 interface

Next Steps for HUNTER

Complete Tight Coupling to Virtual Worlds

- RELAP5
- EMRALD
- GSE’s GPWR

Complete Standalone Software Release

- User Interface
- Quality assurance
- Validation
- Documentation

Develop More Use Cases and Demonstrations

- Currently finishing/documenting SGTR
- Looking at FLEX and balance of plant as determined by industry needs

INL

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